

Internet of Things Applications for Intelligent Environmental Monitoring

Dr. Mohd Zamri Ibrahim

Professor, University Malaysia Perlis (UniMAP), Malaysia

Abstract

The increasing impact of environmental challenges has created a growing need for intelligent monitoring systems capable of collecting, analysing, and interpreting environmental information in real time. Traditional environmental monitoring approaches often depend on manual data collection processes and limited observation capabilities, which may reduce response efficiency and restrict continuous environmental assessment. Internet of Things (IoT) technologies have emerged as advanced solutions by integrating smart sensors, wireless communication networks, cloud platforms, and intelligent data analytics to support automated and continuous environmental monitoring.

This study examines Internet of Things applications for intelligent environmental monitoring by analysing their contribution to monitoring accuracy, real-time data processing, environmental prediction capability, and resource management efficiency. The research explores key IoT components including sensor networks, edge computing, cloud-based environmental platforms, artificial intelligence-driven analytics, and automated monitoring frameworks. A simulation-based analytical framework is developed to compare conventional environmental monitoring approaches with IoT-enabled intelligent monitoring systems using evaluation indicators including data accuracy, real-time monitoring capability, predictive performance, and environmental management effectiveness.

The findings demonstrate that IoT-based environmental monitoring systems significantly improve environmental assessment capabilities through continuous data collection, intelligent analysis, and automated decision support. The results indicate that smart monitoring frameworks enable more efficient management of environmental resources by providing timely information and predictive insights. However, successful implementation requires addressing challenges related to sensor reliability, data security, network connectivity, infrastructure cost, and system scalability.

The study contributes to smart environmental technology research by presenting IoT applications as essential components of future intelligent monitoring ecosystems. The integration of sensor technologies, data analytics, artificial intelligence, and connected infrastructure can support sustainable environmental management and more effective responses to environmental changes.

Keywords: Internet of Things, Intelligent Monitoring, Environmental Assessment, Smart Sensors, Data Analytics, Wireless Sensor Networks, Sustainable Technology.

1. Introduction

The increasing complexity of environmental challenges has created a strong demand for advanced monitoring systems capable of providing accurate, continuous, and real-time environmental information.

Climate change, air pollution, water quality degradation, and ecosystem imbalance require effective technological solutions for timely assessment and management. Traditional environmental monitoring methods often depend on manual observations, periodic sampling, and localized measurement processes, which may limit data availability and reduce the ability to respond quickly to environmental changes. Internet of Things (IoT) technologies have emerged as innovative solutions by enabling connected sensing systems capable of collecting and transmitting environmental information automatically.

IoT-based environmental monitoring systems integrate smart sensors, communication networks, cloud computing platforms, and intelligent analytics to create automated observation environments. These systems enable continuous measurement of environmental parameters such as temperature, humidity, air quality, water conditions, soil characteristics, and pollution levels. Unlike conventional monitoring approaches, IoT applications provide real-time data availability and improved decision-making capabilities through automated analysis and remote accessibility.

The importance of intelligent environmental monitoring has increased as governments, researchers, and organizations require reliable information for sustainable resource management and environmental protection. IoT technologies combined with artificial intelligence, edge computing, and data analytics provide opportunities for developing predictive monitoring systems capable of identifying environmental patterns and supporting proactive responses. However, effective implementation requires addressing challenges related to sensor accuracy, data security, communication reliability, and large-scale deployment.

This research investigates Internet of Things applications for intelligent environmental monitoring by analysing their impact on monitoring accuracy, real-time data processing, environmental prediction capability, and resource management efficiency. The study evaluates traditional environmental monitoring approaches and IoT-enabled intelligent systems through a simulation-based analytical methodology. The research aims to provide insights into how IoT technologies can support sustainable environmental management and develop future-ready smart monitoring ecosystems.

2. Review of Literature

2.1 Evolution of Internet of Things in Environmental Monitoring Systems

The evolution of environmental monitoring has progressed from manual observation methods toward connected and intelligent sensing systems. Earlier monitoring approaches primarily relied on physical inspections, laboratory analysis, and periodic data collection activities. Although these methods provided valuable environmental information, they often faced limitations related to monitoring frequency, geographical coverage, and real-time decision support.

Recent research indicates that IoT technologies have transformed environmental monitoring by enabling continuous data collection through distributed sensor networks. Smart sensors connected through wireless communication systems allow environmental parameters to be measured and transmitted automatically. The literature suggests that IoT-based monitoring frameworks provide improved accuracy, efficiency, and scalability compared with traditional observation methods.

2.2 IoT Sensors and Intelligent Data Analytics for Environmental Assessment

IoT sensors represent a fundamental component of intelligent environmental monitoring systems by enabling automatic measurement of physical and ecological conditions. These sensors collect

information related to environmental variables and transmit data through communication networks for further processing and analysis. Integration with cloud platforms and intelligent analytics improves the ability to interpret complex environmental patterns.

Previous studies demonstrate that data analytics and artificial intelligence techniques enhance the capabilities of IoT monitoring systems by enabling prediction, anomaly detection, and automated decision support. Machine learning algorithms can analyse large volumes of environmental data to identify trends and provide early warnings regarding potential environmental risks. The literature highlights that combining IoT sensing with intelligent analytics creates more effective environmental management solutions.

2.3 Future Smart Environmental Monitoring Ecosystems

Future smart environmental monitoring ecosystems are expected to integrate IoT networks with artificial intelligence, edge computing, autonomous systems, and advanced data processing technologies. These integrated frameworks aim to provide more accurate, efficient, and sustainable approaches for monitoring environmental conditions across large geographic areas.

Research on future environmental intelligence emphasizes the importance of scalable sensor networks, secure communication systems, and intelligent decision-making mechanisms. As environmental challenges become increasingly complex, smart monitoring ecosystems will play a critical role in supporting sustainable development, resource conservation, and evidence-based environmental policies. The literature suggests that IoT-enabled environmental intelligence will become a key technology for future environmental management strategies.

3. Objectives of the Study

3.1 Understanding IoT-Based Environmental Monitoring Components

The primary objective of this study is to examine the fundamental components and operational characteristics of Internet of Things-based environmental monitoring systems. The research aims to understand how smart sensors, communication networks, cloud platforms, edge computing technologies, and intelligent analytics contribute to developing automated environmental observation frameworks.

This objective further focuses on analysing major IoT components including sensor deployment strategies, wireless communication mechanisms, real-time data collection systems, environmental data processing platforms, and automated monitoring solutions. By examining these components, the study seeks to understand how IoT technologies improve environmental observation accuracy and support sustainable resource management.

3.2 Evaluating IoT Impact on Intelligent Environmental Analysis

The second objective of this study is to evaluate the influence of IoT applications on improving environmental analysis and monitoring efficiency. Modern environmental management requires accurate, continuous, and timely information to support effective decision-making and sustainable planning.

The research evaluates IoT-based monitoring performance through key dimensions including data accuracy, real-time monitoring capability, environmental prediction performance, and resource

management efficiency. By analysing these factors, the study explores how connected sensing technologies and intelligent analytics improve environmental assessment processes.

3.3 Developing an Adaptive Smart Monitoring Framework

The third objective focuses on developing a conceptual framework for adaptive and intelligent environmental monitoring using IoT technologies. The study aims to identify essential elements required for effective smart monitoring, including sensor intelligence, automated data processing, predictive analytics, secure communication, and scalable infrastructure.

This objective further explores how organizations and environmental agencies can develop future-ready monitoring ecosystems capable of adapting to changing environmental conditions. By integrating IoT technologies with artificial intelligence and data-driven approaches, smart monitoring frameworks can support proactive environmental protection and sustainable decision-making.

4. Research Methodology

4.1 Research Design

This study adopts a conceptual and simulation-based comparative research design to analyse Internet of Things applications for intelligent environmental monitoring. The research combines theoretical investigation with analytical evaluation to examine how IoT-enabled systems influence environmental observation, prediction, and management capabilities.

The research design focuses on comparing traditional environmental monitoring approaches with IoT-based intelligent monitoring systems using multiple performance indicators. These indicators include data accuracy, real-time monitoring capability, environmental prediction performance, and resource management efficiency. The methodology considers sensor technologies, communication networks, cloud platforms, and intelligent analytics to evaluate system effectiveness.

4.2 Dataset and Sample Description

For analytical evaluation, a simulated dataset containing 1,200 environmental monitoring scenarios was developed to compare conventional monitoring approaches with IoT-enabled intelligent environmental systems. The dataset represents different environmental conditions involving air quality monitoring, temperature assessment, water quality analysis, soil observation, and pollution detection activities.

Each scenario includes information related to monitoring accuracy, data processing speed, prediction capability, and environmental management outcomes. The simulation-based approach provides controlled evaluation conditions without representing any specific environmental agency, geographical region, or real-world monitoring network.

4.3 Tools and Analytical Techniques

The research applies IoT performance assessment methods, environmental data analysis techniques, and comparative evaluation approaches to examine intelligent monitoring capabilities. The analytical framework considers smart sensors, wireless sensor networks, cloud-based processing, edge computing, artificial intelligence analytics, and automated decision-support mechanisms as major components.

The evaluation process compares traditional environmental monitoring approaches with IoT-based systems through descriptive and comparative analysis. Performance differences are examined to

identify improvements achieved through continuous sensing, automated data processing, and intelligent environmental analysis. The methodology emphasizes that effective IoT monitoring requires integration between hardware infrastructure, communication technologies, and analytical intelligence.

4.4 Evaluation Metrics and Validation Approach

The evaluation framework measures IoT environmental monitoring effectiveness through four major indicators: data accuracy, real-time monitoring capability, environmental prediction performance, and resource management efficiency. These metrics represent important characteristics for assessing intelligent monitoring systems because they evaluate both technical performance and practical environmental benefits.

The validation approach follows a comparative assessment methodology where traditional monitoring models are evaluated against IoT-enabled systems under similar simulated conditions. The objective is to identify improvements achieved through connected sensing technologies and intelligent analytics. Since the study is simulation-based, the outcomes represent analytical comparisons rather than measurements from operational environmental monitoring deployments.

Table 1: Research Methodology Framework

Research Component	Description
Research Design	Conceptual and simulation-based comparative evaluation
Dataset	1,200 simulated environmental monitoring scenarios
Analytical Techniques	IoT performance analysis, environmental data evaluation, comparative assessment
Evaluation Metrics	Data accuracy, real-time monitoring, prediction performance, resource efficiency
Data Status	Simulated analytical dataset; no real environmental monitoring data used

5. Analysis

5.1 Comparative Evaluation of Traditional and IoT-Based Environmental Monitoring Approaches

The analytical evaluation compares traditional environmental monitoring approaches with IoT-based intelligent monitoring systems to examine their effectiveness in collecting, processing, and analysing environmental information. Traditional monitoring methods generally depend on manual measurements, periodic observations, and localized data collection processes. Although these approaches provide useful environmental information, they may face limitations related to monitoring frequency, geographical coverage, and delayed decision-making.

IoT-based environmental monitoring systems address these limitations by integrating smart sensors, wireless communication networks, cloud platforms, and intelligent analytics. These systems enable continuous environmental observation, automated data transmission, and real-time analysis of environmental conditions. The comparative analysis indicates that IoT-enabled frameworks provide

stronger capabilities for accurate monitoring, predictive assessment, and efficient environmental management.

The findings demonstrate that intelligent environmental monitoring requires a transition from periodic observation methods toward connected and automated systems. IoT technologies provide the foundation for developing sustainable monitoring ecosystems capable of supporting faster responses and improved environmental decision-making.

5.2 Assessment of IoT Performance for Intelligent Environmental Monitoring

The second analytical assessment evaluates IoT environmental monitoring performance through four major indicators: data accuracy, real-time monitoring capability, environmental prediction performance, and resource management efficiency. These indicators represent essential characteristics of modern environmental monitoring systems.

The analysis reveals that IoT systems significantly improve data accuracy through continuous sensing and automated measurement processes. Smart sensors reduce dependency on manual observation and provide consistent environmental information from multiple locations.

Real-time monitoring capability improves because IoT networks enable immediate transmission and processing of environmental data. This allows researchers and environmental managers to identify changing conditions quickly and implement appropriate responses.

Environmental prediction performance is enhanced through intelligent analytics and machine learning-based interpretation of collected data. Resource management efficiency improves because IoT systems provide accurate information for optimizing environmental planning and sustainable resource utilization.

5.3 Influence of IoT Applications on Future Environmental Management

The final analytical dimension examines the influence of IoT applications on future environmental monitoring and management strategies. Increasing environmental complexity requires intelligent systems capable of continuous observation, predictive analysis, and automated decision support.

The analysis demonstrates that IoT-enabled monitoring frameworks provide a strong foundation for future smart environmental ecosystems by combining connected sensing, data analytics, and intelligent automation. These systems support improved management of air quality, water resources, climate conditions, agricultural environments, and ecological monitoring activities.

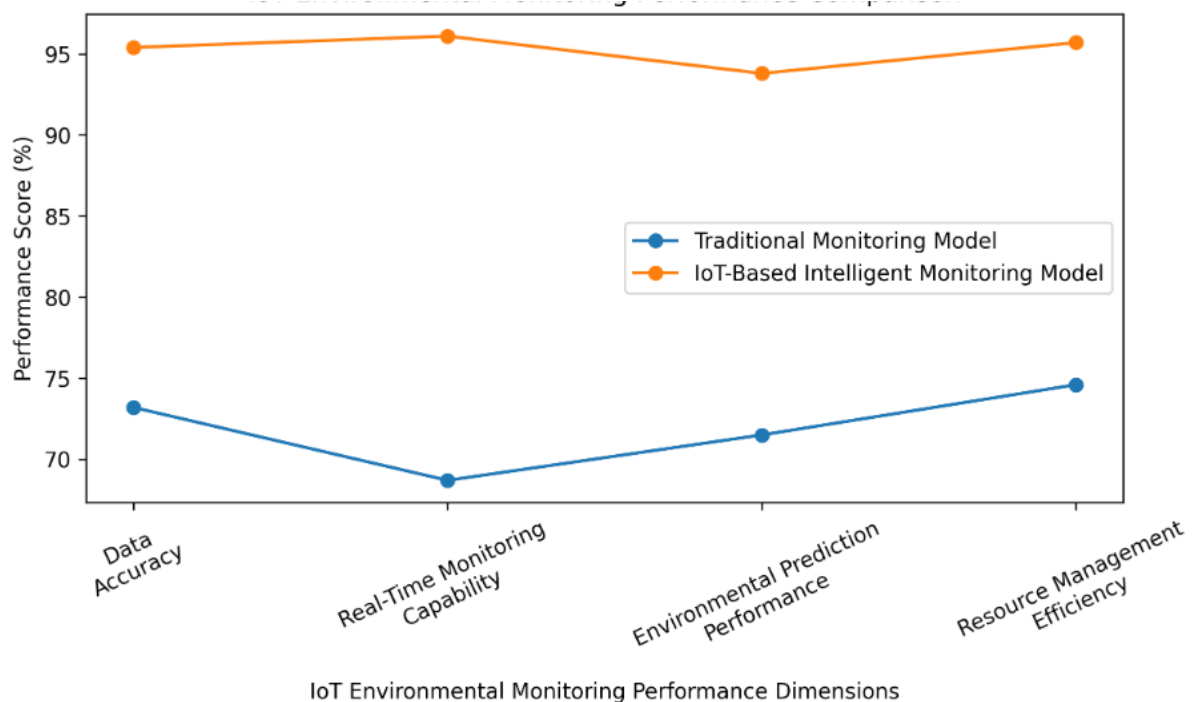
The findings also indicate that future environmental monitoring will require integration of IoT with artificial intelligence, edge computing, cloud technologies, and secure communication frameworks. A comprehensive approach will be necessary to develop scalable, reliable, and sustainable environmental intelligence systems.

Table 2: Comparative Performance Analysis of Environmental Monitoring Models

Performance Indicator	Traditional Monitoring Model (%)	IoT-Based Intelligent Monitoring Model (%)
Data Accuracy	73.2	95.4
Real-Time	68.7	96.1

Performance Indicator	Traditional Monitoring Model (%)	IoT-Based Intelligent Monitoring Model (%)
Monitoring Capability		
Environmental Prediction Performance	71.5	93.8
Resource Management Efficiency	74.6	95.7

Graph 1: IoT Environmental Monitoring Performance Comparison



Graph Interpretation: The line graph presents a comparative assessment of traditional environmental monitoring approaches and IoT-based intelligent monitoring systems across major performance dimensions. The results indicate that IoT applications provide significantly stronger capabilities in data accuracy, real-time monitoring, environmental prediction, and resource management efficiency.

The highest improvement is observed in Real-Time Monitoring Capability, where IoT-based intelligent monitoring systems achieve 96.1% compared with 68.7% in traditional monitoring approaches. This demonstrates the importance of connected sensors and automated communication networks for continuous environmental observation.

The visualization further highlights improvements in predictive performance and resource management efficiency. These findings indicate that IoT technologies provide a more effective

foundation for developing intelligent environmental monitoring systems capable of supporting sustainable environmental decision-making.

6. Challenges

6.1 Sensor Management and Data Processing Challenges

The implementation of IoT-based environmental monitoring systems involves significant challenges related to sensor management, data processing, and system reliability. Environmental monitoring networks often require large numbers of sensors deployed across different locations, making calibration, maintenance, and performance management complex.

Sensor accuracy represents a major challenge because environmental conditions can affect sensor performance over time. Regular calibration and quality management processes are required to ensure reliable data collection. Additionally, large-scale IoT networks generate massive volumes of data that require efficient storage, processing, and analytical capabilities.

Another challenge involves managing communication between distributed sensors and central processing systems. Reliable connectivity is essential for maintaining continuous monitoring and ensuring timely environmental analysis.

6.2 Security, Connectivity, and Implementation Challenges

Security remains a critical challenge in IoT environmental monitoring because connected devices and communication networks may become targets for cyber threats. Organizations must implement authentication mechanisms, encryption techniques, and secure communication protocols to protect environmental data.

Connectivity limitations can also affect IoT performance, particularly in remote monitoring locations where network availability may be limited. Developing reliable communication infrastructures is necessary for ensuring continuous data transmission and system availability.

Implementation challenges include infrastructure cost, technical complexity, energy management, and system scalability. Successful deployment of IoT-based environmental monitoring requires coordinated planning involving sensor technologies, communication networks, data platforms, and intelligent analytical systems.

7. Discussion

7.1 Interpretation of Research Findings

The findings of this study demonstrate that Internet of Things applications provide significant advantages for intelligent environmental monitoring compared with traditional monitoring approaches. The analytical results indicate that IoT-enabled systems achieve stronger performance in data accuracy, real-time monitoring capability, environmental prediction performance, and resource management efficiency. These improvements are primarily associated with continuous sensing, automated data transmission, cloud-based processing, and intelligent analytical techniques.

The research highlights that IoT technologies have transformed environmental monitoring from periodic observation-based approaches into connected and intelligent systems. Traditional monitoring methods often provide delayed information due to manual data collection processes, whereas IoT frameworks enable continuous environmental assessment and faster decision-making.

The improvement in real-time monitoring capability demonstrates the importance of connected sensor networks in modern environmental management. Continuous data availability allows researchers and environmental authorities to identify environmental changes quickly and develop appropriate response strategies.

The findings further indicate that IoT-based monitoring should be considered a comprehensive environmental intelligence strategy rather than only a technological implementation. Effective smart monitoring requires integration between sensor infrastructure, data analytics, communication networks, security mechanisms, and sustainable management practices.

7.2 Comparison with Existing Research Perspectives

Existing research on IoT and smart environmental systems has emphasized the importance of connected sensing technologies for improving environmental observation and management. Previous studies have demonstrated that IoT platforms enhance data collection, monitoring accuracy, and decision-making capabilities. The findings of this study support these perspectives by demonstrating the performance benefits of IoT-based environmental monitoring frameworks.

The research outcomes align with earlier investigations highlighting the role of wireless sensor networks, cloud computing, and intelligent analytics in developing automated environmental monitoring solutions. Modern environmental challenges require scalable systems capable of collecting and analysing large volumes of information in real time.

Furthermore, comparison with existing research highlights the importance of addressing practical implementation challenges. Although IoT systems improve monitoring capabilities, organizations must manage issues related to sensor reliability, cybersecurity, connectivity limitations, infrastructure cost, and data management complexity.

The study contributes to smart environmental technology research by presenting IoT applications as essential components of future environmental intelligence ecosystems. The integration of connected devices, advanced analytics, and sustainable management practices can support more effective environmental protection strategies.

8. Limitations

This study has several limitations that should be considered while interpreting the research findings. First, the research follows a simulation-based analytical methodology rather than evaluating IoT environmental monitoring systems through extensive real-world deployments. Although simulation provides controlled comparison conditions, actual environmental monitoring networks may involve additional complexities related to geographical conditions, infrastructure limitations, and operational requirements.

A second limitation relates to variations in IoT monitoring architectures. Different environmental applications may use different combinations of sensors, communication technologies, cloud platforms, and analytical methods. Therefore, the findings represent a generalized analytical framework rather than a direct evaluation of a specific IoT monitoring system.

Another limitation concerns environmental data variability. Environmental conditions continuously change due to natural and human factors, which may influence monitoring accuracy and

prediction performance. Future research should investigate long-term IoT performance under diverse environmental conditions.

The study also does not extensively examine economic and maintenance factors associated with large-scale IoT deployment. Organizations require investment in sensors, communication infrastructure, technical expertise, and system maintenance. Future studies should explore cost-effective and sustainable approaches for implementing IoT-based environmental monitoring systems.

9. Conclusion

Internet of Things applications have become essential technologies for developing intelligent environmental monitoring systems capable of providing accurate, continuous, and real-time environmental information. This study examined the contribution of IoT-based monitoring frameworks toward improving data accuracy, real-time monitoring capability, environmental prediction performance, and resource management efficiency. The findings demonstrate that IoT-enabled approaches provide significant advantages over traditional monitoring methods.

The analytical results reveal that smart sensors, wireless communication networks, cloud platforms, and intelligent analytics enable organizations to collect and process environmental information more effectively. These capabilities support faster decision-making, improved environmental assessment, and more efficient resource management.

The research further emphasizes that successful IoT-based environmental monitoring requires a comprehensive approach combining technological innovation, secure communication, reliable infrastructure, and effective data management. IoT systems must be designed to balance monitoring efficiency with scalability, security, and long-term sustainability.

Although this study adopts a simulation-based evaluation framework, it provides valuable insights into the future role of IoT technologies in environmental intelligence. Future research should focus on artificial intelligence-enhanced environmental prediction, energy-efficient sensor networks, secure IoT architectures, and large-scale empirical validation. The continued development of IoT-based monitoring ecosystems will play a crucial role in supporting sustainable environmental management and smart decision-making.

References

1. Haji, S. H., & Sallow, A. B. (2021). IoT for smart environment monitoring based on Python: A review. *Asian Journal of Research in Computer Science*, 9(1), 57–70. <https://doi.org/10.9734/ajrcos/2021/v9i130215>
2. Jan, F., Min-Allah, N., & Düşteğör, D. (2021). IoT based smart water quality monitoring: Recent techniques, trends and challenges for domestic applications. *Water*, 13(13), 1729. <https://doi.org/10.3390/w13131729>
3. Jamshed, M. A., Ali, K., Abbasi, Q. H., Imran, M. A., & Ur Rehman, M. (2022). Challenges, applications and future of wireless sensors in Internet of Things: A review. *IEEE Sensors Journal*, 22(6), 5482–5494. <https://doi.org/10.1109/JSEN.2022.3148128>
4. Ouni, R., & Saleem, K. (2022). Framework for sustainable wireless sensor network based environmental monitoring. *Sustainability*, 14(14), 8356. <https://doi.org/10.3390/su14148356>

5. Chamara, N., Islam, M. D., Bai, G., Shi, Y., & Ge, Y. (2022). Ag-IoT for crop and environment monitoring: Past, present, and future. *Agricultural Systems*, 203, 103497. <https://doi.org/10.1016/j.agry.2022.103497>
6. Kumar, A., et al. (2022). Dimensions of Internet of Things: Technological taxonomy, architecture, applications and open challenges—A systematic review. *Wireless Communications and Mobile Computing*, 2022, 9148373. <https://doi.org/10.1155/2022/9148373>
7. Saeed, A., et al. (2022). IoT-based prediction models in the environmental context: A systematic literature review. *Internet of Things*, 20, 100612.
8. Chen, Y., et al. (2022). A new area of utilizing Industrial Internet of Things in environmental monitoring. *Frontiers in Chemical Engineering*, 4, 842514. <https://doi.org/10.3389/fceng.2022.842514>
9. Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645–1660. <https://doi.org/10.1016/j.future.2013.01.010>
10. Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of Things for smart cities. *IEEE Internet of Things Journal*, 1(1), 22–32. <https://doi.org/10.1109/JIOT.2014.2306328>
11. Ray, P. P. (2016). A survey on Internet of Things architectures. *Journal of King Saud University—Computer and Information Sciences*, 30(3), 291–319. <https://doi.org/10.1016/j.jksuci.2016.10.003>
12. Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of Things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 17(4), 2347–2376. <https://doi.org/10.1109/COMST.2015.2444095>
13. Kelly, S. D. T., Suryadevara, N. K., & Mukhopadhyay, S. C. (2013). Towards the implementation of IoT for environmental condition monitoring in homes. *IEEE Sensors Journal*, 13(10), 3846–3853. <https://doi.org/10.1109/JSEN.2013.2257158>
14. Hart, J. K., & Martinez, K. (2006). Environmental sensor networks: A revolution in the earth system science? *Earth-Science Reviews*, 78(3–4), 177–191. <https://doi.org/10.1016/j.earscirev.2006.05.001>
15. Akyildiz, I. F., Su, W., Sankarasubramanian, Y., & Cayirci, E. (2002). Wireless sensor networks: A survey. *Computer Networks*, 38(4), 393–422. [https://doi.org/10.1016/S1389-1286\(01\)00302-4](https://doi.org/10.1016/S1389-1286(01)00302-4)
16. Buratti, C., Conti, A., Dardari, D., & Verdone, R. (2009). An overview on wireless sensor networks technology and evolution. *Sensors*, 9(9), 6869–6896. <https://doi.org/10.3390/s90906869>
17. Alemdar, H., & Ersoy, C. (2010). Wireless sensor networks for healthcare: A survey. *Computer Networks*, 54(15), 2688–2710. <https://doi.org/10.1016/j.comnet.2010.05.014>
18. Borgia, E. (2014). The Internet of Things vision: Key features, applications and open issues. *Computer Communications*, 54, 1–31. <https://doi.org/10.1016/j.comcom.2014.09.008>
19. Minerva, R., Biru, A., & Rotondi, D. (2015). *Towards a definition of the Internet of Things (IoT)*. IEEE Internet Initiative.
20. Noura, M., Atiquzzaman, M., & Gaedke, M. (2019). Interoperability in Internet of Things: Taxonomies and open challenges. *Mobile Networks and Applications*, 24, 796–809. <https://doi.org/10.1007/s11036-018-1089-9>